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THE ARRANGEMENT OF THE CANCELLATED OSSEOUS TISSUE IN THE FOOT, AS ILLUSTRATIVE OF THE MECHANISM OF THAT ORGAN.—By H. V. Carter, M.D.

Presented to the Medical and Physical Society, October, 1863.

e hand of man has, since the monograph of Charles Bell red, been to anatomists a favourite topic on which to in illustration of the mechanical structure of the human ; and the foot is no less worthy of notice, although ful- a more limited rule.

ether in the scale of general development the pedal organ de the manual, whether man alone possesses a foot, y so called, and the corresponding part in the anthropo- ous apes be a modified prehensile instrument or not, uestions of some interest to the transcendental anatomist, ey will not be broached here.

e following brief notes refer only to some minute points ucture which curiosity led me to inquire into during a absence from Bombay, nearly three years ago; and they fered rather with the object of introducing variety into oceedings of this meeting, than with the idea of bringing rd anything very new, although the details they contain been independently worked out.

e foot is an instrument of station and locomotion, and ore requires strength or firmness, and elasticity, as well egree of mobility; and it is in the union of these appa- incongruous properties that we find mechanical design evident. At present I refer only to the means by which ure or weight is supported and concussion sustained

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with the most economical use of material, selecting for illustration the osseous framework of this organ.

The bones of the foot are, relatively to their office, small and light, and yet they are little liable to fracture in all ordinary avocations. This is mainly owing to the structure of the cancellated tissue of which they are chiefly composed.

As is well known, cancellous or reticular osseous tissue is made up of plates or laminæ and beams or columns of bone, connected by cross pieces, and while more or less parallel and curved, placed vertically or obliquely to the articular surfaces and shaft; much in the same way, in fact, and with equal intent, as the poles of a scaffolding, or more correctly, the girders of a bridge, &c.

At the ends of such columns, and along the edges of the plates, pressure of all kinds is most advantageously sustained or transmitted; so that by examining the arrangement of the principal elements of this reticular tissue we may readily infer the direction and comparative degree of pressure it is calculated to bear.

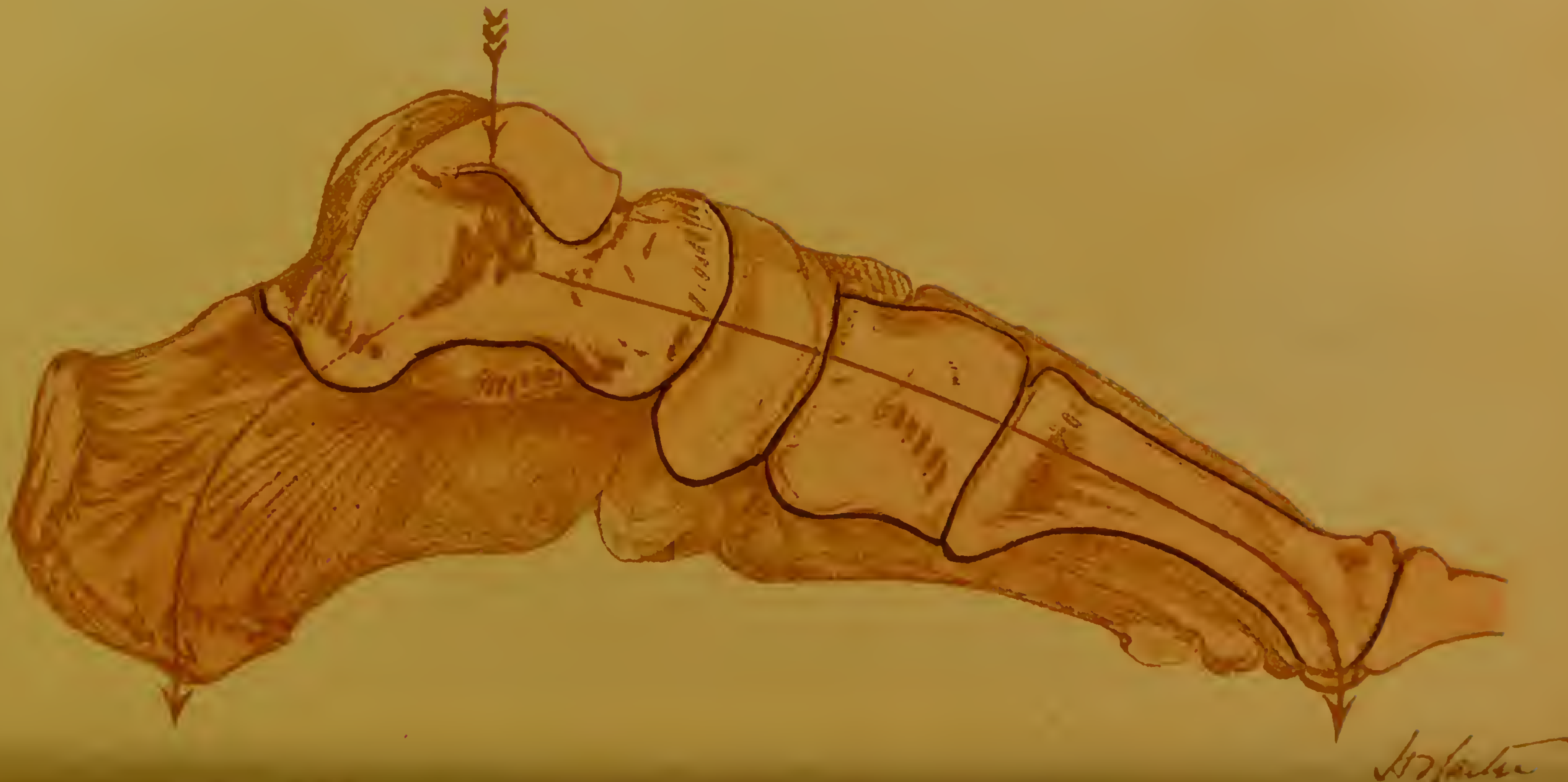
The lines of force or greatest pressure passing directly between the points of contact or support, it is evident that an iron or wooden structure (*e.g.*) in appearance light and flimsy, may be really of great strength; and an ordinary building so dissected as to leave only the parts directly affording support would have such an appearance. The cancellated tissue of the bones is constructed precisely for this purpose, of giving the requisite strength with least possible expenditure of material.

For illustrations' sake, let us regard the "short" bones of the skeleton as so many beams of varying length, and then apply the requisite principles of mechanics, according to which even solid beams may be regarded (in considering the strains borne in their interior) as composed of separate laminæ,* the

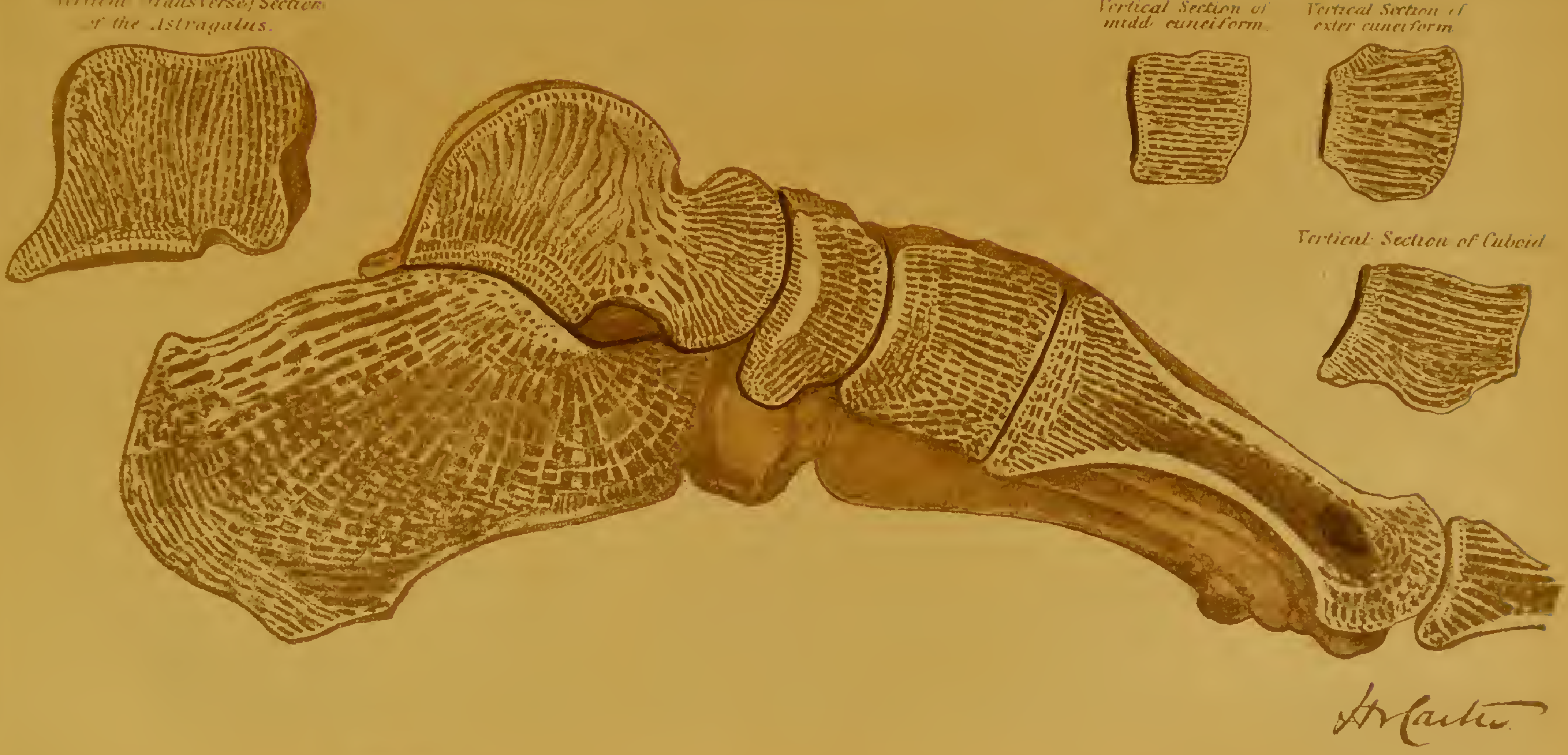
* See Professor Airy's Researches, published in the Philosophical Transactions, 1862.

A

THE ARCH OF THE FOOT. — the arrows show the direction of vertical pressure.



VERTICAL (LONGITUDINAL) SECTION OF THE BONES OF THE ARCH.
showing the arrangement of the Cancellous Tissue



interspaces of which, not being directly effective in sustaining pressure, are so far superfluous; and here will be found the explanation of "cancelli", or retal intervals, in the tissue under investigation—so far is a true economy of material evidenced in the framework of the body.*

On regarding the foot of man—the posture being erect—it is seen that the weight of the body is received behind the centre of the arch formed by the inner side of the foot (and there is a reason for this), reaching the ground at the two ends of the arch ; and a vertical section of the bones reveals an interior structure entirely adapted to meet and conduct this weight backwards and downwards, and forwards and downwards. Thus, section of the *astragulus* shows a radiating disposition of the fibres and plates, indicating a decomposition of the pressure, little of it passing vertically downwards; and the os calcis beneath and behind, which receives the greater moiety, admirably displays in section how the pressure reaches the ground at the heel ; while the *scaphoid cuneiform,* and *metatarsal* bones similarly bisected, exhibit the arrangement by which the weight directed forward is conducted, with an intermediate "brake" of joints, &c., to the ground at the front of the sole. See the figures **A** and **B**.

Force applied to the foot in an horizontal direction, except in the case of direct blows on the heel or toes, only occurs with any frequency in such actions as jumping from a height, &c. Its distribution is now more complicated than when applied vertically, and I shall make use of Mr. Ward's clear descrip-

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* The effectiveness of arrangement is shown in the strength possessed by cancellous tissue; *e. g.*, a small cube from the femur, weighing 54 grains, will support a weight of 6 cwt., with the result of its upper half only being crushed. A cubic inch of solid elm wood gives way under 1,284 lbs., or about two and a-half times the weight beneath which the cube of reticular tissue began to yield.

Quoted from *Ward's Human Osteology,* 2nd edition, 1848 ; an admirable work, elsewhere laid under contribution in this Paper.

tions (*loc. cit.*) in attempting to trace the details. In jumping, &c., the whole weight of the body, then, moving with considerable velocity is received more or less obliquely by the toes when they touch the ground; "part of the force of impact bends the ankle-joint, depresses the heel, and tells upon the muscles of the calf, which yield to it in the manner of a spring, while another portion, which increases as the foot is pointed more directly downward during the concussion, passes longitudinally through the tarsus to the tibia," and fibula. The course taken through foot will be readily understood by the aid of Figure **C**, which represents the bones as seen from above; the straight arrows show the direction in which the force arrives along the five *metatarsal* bones, and the bent arrows its subsequent decomposition; a part passing onwards by the dotted lines, and part outwards, of which the most is transmitted by the three outer *metatarsal* bones, and falls on the *cuboid;* this bone having its base turned inwards is well calculated to meet the shock. "That portion of the force of impact which passes from the *cuneiform* bones to the *scaphoid* proceeds thence through the *astragalus* to the *tibia*" and fibula. In its progress through the tarsus it traverses a bend formed by the obliquity in opposite directions of the cuneiform bones and the neck of the astragalus. This curve (indicated by the dotted lines) "yields beneath concussion, its convexity increasing during the passage of the force, and being restored immediately afterwards (by the action of the ligaments and tendons) to its previous condition." "The outer division of the tarsus presents a more massive structure, less elastic, but in an equivalent degree more rigid than the inner. Shocks transmitted along the fourth and fifth metatarsal bones pass almost directly through the cuboid to the calcaneum" in the direction of the dotted line.

"The explanation of this difference in the mechanical construction of the opposite sides of the tarsus is obvious. It is upon the ball of the great toe and the adjacant portions of the

sole that we usually alight in jumping and similar actions, it is therefore by the inner division of the tarsus that the most numerous and most violent concussions are sustained, and that elasticity is chiefly required. Hence the advantage of its numerous obliquely-pointed bones and its curvilinear arrangement. The outer division on the other hand acts principally as a lever stretching backwards from the metatarsus, beneath the astragalus, to receive the insertion of the great tendon of the heel. To this purpose it is adopted by its comparative rigidity, and by the almost rectilinear disposition of its bones, while its inferior elasticity involves no additional liability to fracture."

The foregoing remarks will serve to introduce and elucidate the special subject of this communication, which is—the arrangement of the cancellated osseous tissue in the bones of the foot; and I think it will be seen after the description which I shall give, from my own observations, of this arrangement, that there is a very striking adaptation of structure to mechanism in this as in numerous other better known instances occurring in the human body.

I cannot but mention what is to me a new point, namely, that the osseous laminæ are also found to be arranged in lines corresponding in direction with those of traction exerted on the bones by the tendons inserted into them; a reference to the drawing appended must suffice for evidence at present.

The structure of each bone will now be described, as displayed in sections made vertically, longways, and across, and also horizontally; the specimens actually used lie on the table for inspection. I will only add that for study either the well-dried bones of an adult subject should be selected, or else those procurable should be well charred in the fire, in order to destroy fat and other organic matter occupying the cancelli, which otherwise will not have the lamellæ forming them clearly defined.

I.—INNER ROW OF TARSAL BONES.

1.—Astragalus—Three Sections.

a.—*Longitudinal Vertical Section* displays a series of plates seen almost on their flat surfaces, inclined towards each other and diverging from the upper convex articular surface, where they commence rather as multiplied, short columns prependicularly disposed downwards and forwards to the head of the bone, some reaching the scaphoidal surface, others that articulating with the inferior calcaneoscaphoid ligament, and others the anterior calcanean facet; they are least marked about the neck, and are absent opposite to the interosseous groove, where is no pressure. Those plates passing downwards and backwards reach the posterior concave calcanean facet, and breaking up into small columns, perpendicularly arranged to that surface are here connected by cross ties.

b.—*Transverse Vertical Section.*—The same plates are seen descending in slightly curved lines from the upper tibial articular surface to the calcanean: they are nearly parallel to each other, and to the malleolar facets, where however they are laid in a different plane, and arranged so as to sustain lateral pressure. This is most apparent on the outer side, where the fibula joins, the design being obviously to meet the shock of blows on the outer ankle; at the inner ankle the laminæ are disposed rather to bear vertical weight or pressure.

c.—*Horizontal Section.*—The same plates are seen on edge, passing from behind forwards the whole length; at the inner or tibial side, being slightly curved, they impinge on the articular surface there, and at the outer side they are more distinctly turned to the fibular facet, falling prependicularly upon it. Forwards, the laminæ gradually diverge to the convex head of the bone in a manner best adapted to distribute, or receive, pressure at the front. The view exhibited by this section is well worthy of study, as showing how force applied laterally at the ankle-joint, or received from the front (as in jumping)

is conducted in such a manner as to be gradually dissipated, the strong ligaments around doubtless taking a large share.

2.—Scaphoid—Two Sections.

a.—*Horizontal.*—Starting behind in a dense layer (characteristic, as appears, of a concave surface) the columns radiate forwards to the three smaller facets, and they are best marked externally. In the tuberosity at the inner side the fibres are not so close or regular (there being no articular surface here), and several converge to its most prominent point, where the tendon of the *tibialis anticus* muscle is inserted.

b.—*Vertical Section.*—The columns, straight and close-set, pass forward nearly parallel to each other, some descending to the tuberosity.

3.—Internal Cuneiform—Two Sections.

a.—*Horizontal.*—Well-marked laminæ are seen running parallel, and directly between the articular surfaces; notice those laterally disposed, where the middle wedge-bone joins on, and compare with the bent arrow in Fig. **C**.

b.—*Vertical.*—Columns formed by the edges of the laminæ are shown radiating in straight lines from the concave to the anterior convex articular surface. A set of fibres is also seen directed from the tuberosity upwards and forwards, having, no doubt, the same office as those found in the corresponding tubercle of the scaphoid bone.

4.—Middle Cuneiform—Two Sections.

a.—*Horizontal.*—Flat plates, now seen on their surfaces, run the whole length of the bone from behind forwards ; a few are lateral on the outer side.

b.—*Vertical.*—The same laminæ are here seen on their edges.

5.—External Cuneiform—Two Sections.

a.—*Horizontal.*—Flat plates, now seen on their surfaces, run the whole length, and are connected by short vertical columns,

which are sometimes aggregated in thick plates passing in a curved direction towards the articular facet for the cuboid bone from the anterior extremity ; these should be compared with the bent arrow in Fig. C.

b.—*Vertical.*—The same laminæ on their edges are here displayed, and are seen to diverge slightly from the posterior concave articular surface.

II.—OUTER ROW OF TARSAL BONES.

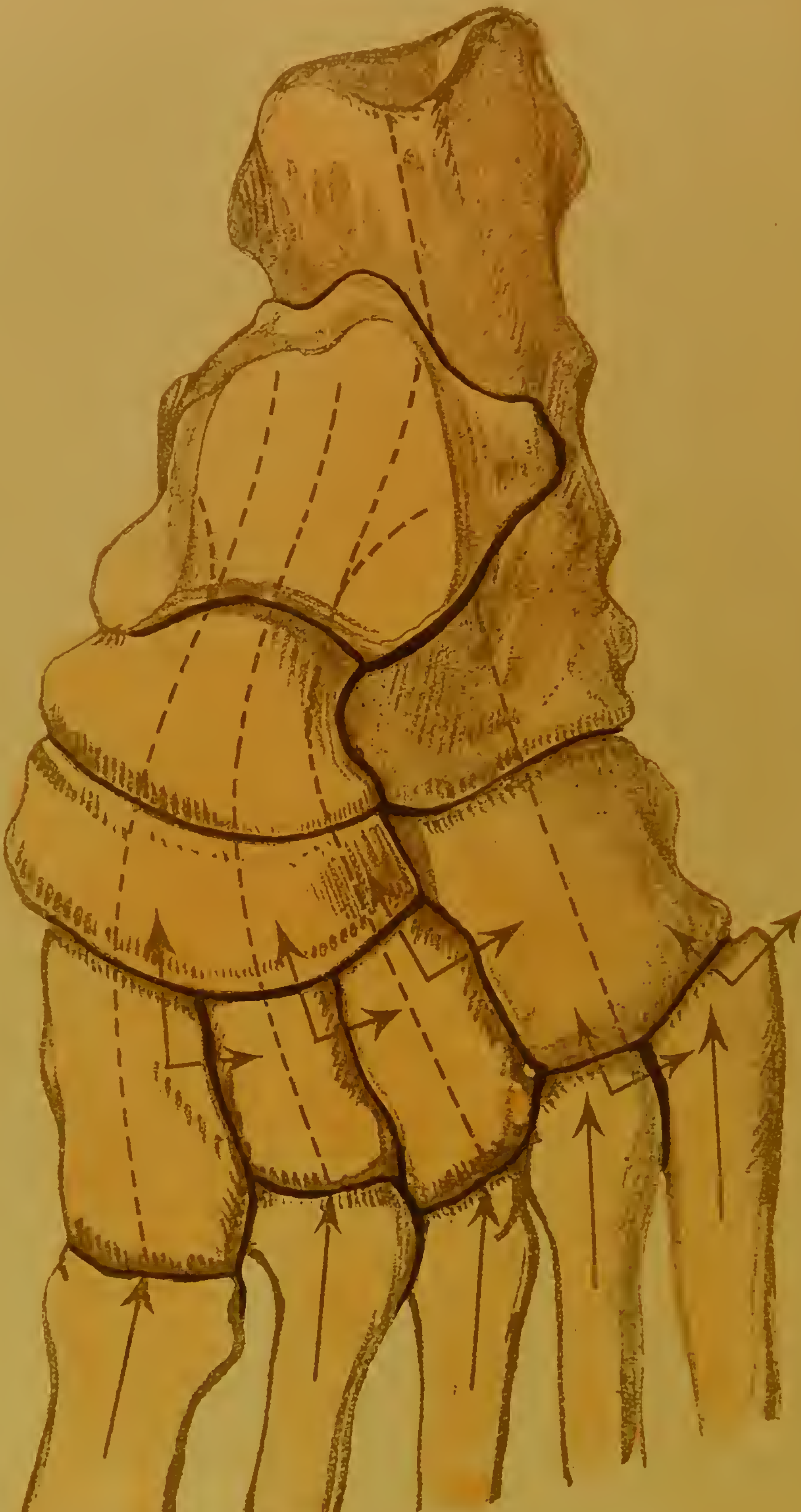
1.—Os Calcis—Two Sections.

a.—*Vertical Section.*—This is one of the most striking of the series. I possess an admirable specimen, from which the following short description is given. Most of the plates and columns radiate from the upper convex articular surface downwards and backwards, some reaching the tuberosity, others extending to the inferior or plantar surface ; the design in each case being very obvious. A second set of laminæ passes from the upper concave facet and the depression behind it, in a radiating manner, forwards towards the cuboid bone ; but directly beneath that depression (which corresponds to the interosseous groove) the osseous tissue becomes much rarified, a few straggling vertical fibres alone being seen, and the reason is obvious, namely, that in this place no pressure is received from the weight of the body.

There may also be noticed, thirdly, a number of delicate fibres intersecting the set first named, which form a series of inverted arches passing between the tuberosity and the plantar surface. It is evident that these, besides binding together the large divergent laminæ, must directly meet the strain of the strong *Tendo Achillis.*

b.—*Horizontal.*—Laminæ are seen passing from one end to the other, being especially well-marked, and somewhat convergent, where impinging on the cuboidal facet, whence a shock from blows, &c., is oftenest received. They are nowhere defi-

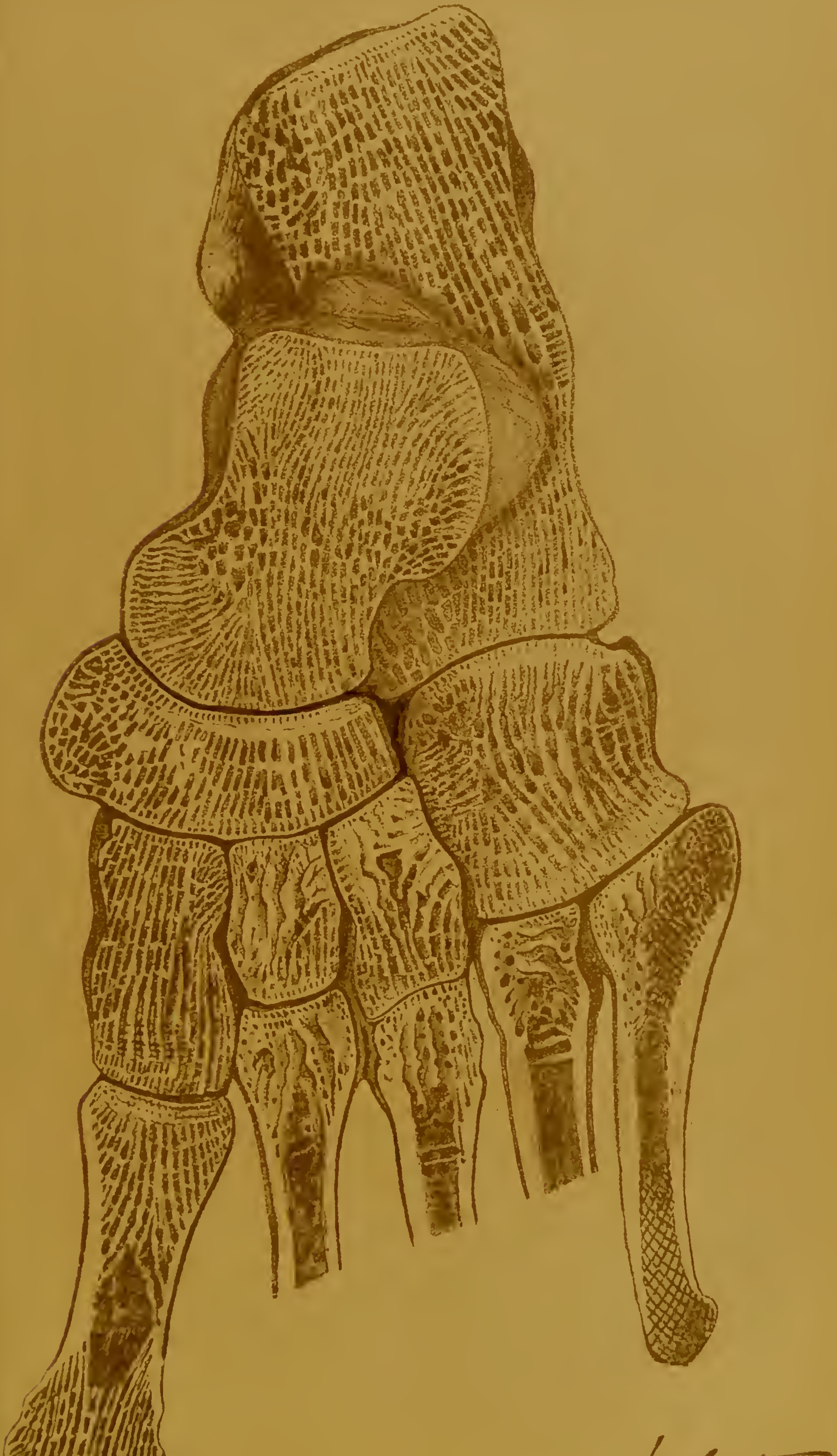
DORSUM OF FOOT – showing lines of pressure resulting from force applied at the toes.



Modified from Ward

TRANSVERSE SECTION OF BONES OF FOOT

showing the arrangement of the Cancellous Tissue



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cient; and their disposition, as now shown, manifests in a very striking manner their adaptation to meet pressure such as a study of the mechanism of the foot shows to be at times inevitable: compare the figures **C** and **D** for other details here omitted.

2.—Cuboid Bone—Two Sections.

a.—*Vertical.*—Long plates run from behind forwards, radiating from the posterior concave facet; some pass down to the grove and ridge in the under surface of this bone (where the strain of tendons and ligaments is often incurred), but most go forwards to the metatarsal articular facets, where force from the front impinges.

b.—*Horizontal.*—Most of the laminæ are here seen to have a curved direction, falling perpendicularly on the articular surfaces in front and behind. The cancelli are very open near the outer edge, where no pressure is borne. A set of cross laminæ is seen at the facet for the outer cuneiform bone, which entirely corresponds with the requirements inferable from mechanical considerations: see again the figures for details.

The Metatarsal and Phalangeal Bones.

In the *metatarsal* bones we observe the walls of the cancelli at the two extremities of the shaft to be disposed in a series of laminæ radiating from the articular surfaces to the compact walls of the shaft. The laminæ are in various planes, and the object of their general arrangement is sufficiently obvious, namely, to afford strength in the long diameter of the bone at least cost of material.

The *phalanges* are constructed on similar principles, which, however, I do not now intend to discuss in further detail.

In conclusion, some apprehension arises in my mind, that the above remarks may be regarded as needlessly prolix; if so, I would only ask those present to examine for themselves the specimens and the details I have given, and they will there,

I venture to think, entering into the spirit of the inquirer, partake of the interest which the subject itself affords to us as medical men, and also of the pleasure naturally felt by every educated person in tracing the evidences of design universally prevalent in animated nature.

Human anatomy, I would add, needs now more than ever to be taught in connection with the natural sciences, a knowledge of which is daily becoming more appreciated by all classes of the people.

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